Golder Associates

TECHNICAL MEMORANDUM

Date:	July 18, 2012	**Project No.:**	093-81962.0007
To:	Chris Garrett, P. HGW.	**Company:**	SWCA Environmental Consultants
From:	Jennifer Patterson and George Annandale	**Email:**	JMPatterson@Golder.com GAnnandale@Golder.com

RE: GEOMORPHIC ASSESSMENT OF BARREL CREEK

Golder Associates Inc. (Golder) was requested to conduct a qualitative geomorphic assessment of Barrel Creek. The goal was to determine the current geomorphic condition and develop an opinion on potential geomorphic changes that could occur with the development of the Rosemont Mine. This letter presents observations from the fieldwork and opinions on potential geomorphic changes that might result due to proposed development of Rosemont Mine.

1.0 INTRODUCTION

Barrel Creek is an ephemeral arroyo located about 25 miles southwest of Tucson (Figure 1). Historic downcutting is evidenced by relatively high banks that are near vertical. This cross-sectional geometry is typical for streams in the arid and semi-arid West. Water flows in the creek only after local precipitation events occur within the watershed. The average annual precipitation estimated at the Rosemont Mine site is 17 inches (USFS 2011). The majority of the precipitation falls during the monsoon period from early July to late August. During the monsoon period, intense thunderstorms build in the late afternoon causing heavy precipitation and flash floods. Streams such as these have extremely high sediment transport rates (for example, Reid, et al., 1998 and Greenbaum and Bergman 2006).

2.0 FIELD OBSERVATIONS

Ms. Jennifer Patterson and Dr. George Annandale conducted a field assessment of Barrel Creek from the headwaters to the confluence with Davidson Canyon on May 1 and 2, 2012. Photographic documentation of the site is recorded from upstream to downstream in the Photographs section below. The photographs illustrate the typical observations from the site.

Two important, geomorphic observations were made during the field visit. The first is that the system is sediment-transport limited. The second is that there is bedrock grade control within the creek upstream of the confluence with Davidson Canyon. Each of these observations is detailed below.

2.1 Sediment-transport Limited

When evaluating the potential impacts for a system, one should consider whether the system is sediment-supply limited or sediment-transport limited. Sediment-supply limited means that the river is transporting as much sediment as is available. The riverbed in a sediment-supply limited system will be composed of an armor layer that is transported only during relatively high flows or the bed may be composed of bedrock. An extreme example of sediment-supply limited is "hungry water" that can occur downstream of a dam.

Sediment-transport limited is the exact opposite. There is more sediment in the system than the river can transport during normal or even flood-flow conditions. The sediment-transport limited system is common in ephemeral streams, because of the flashy nature of these systems. A large precipitation event will create a pulse of water flowing down the creek. On the rising limb of the hydrograph, the water picks up more and larger particles of sediment and transports them downstream. However, the hydrograph is short. Typical hydrographs contain multiple peaks due to slugs of precipitation from different areas of the watershed (Reid, et al., 1996). The sediment is dropped out of suspension on the falling limb of the hydrograph. Sediment is transported downstream, but it is deposited a relatively short distance from the source. In a sediment-transport limited system, the bed material will be poorly sorted (i.e., all gradations are present). The bed material will be loose, and an armor layer will not be present (Hassan, et al., 2005).

Barrel Creek is a classic example of a sediment-transport limited system. It is ephemeral, which means that the water only flows occasionally and usually after a precipitation event. The flashy nature of the flows means that sediment is not transported on a regular basis. The bed is composed of a thick layer of unconsolidated sands, gravels, and cobbles. These types of sediment are readily transported during any significant flows within the creek, but the transport stops as quickly as it starts.

Evidence observed in the field confirming that Barrel Creek is a sediment-transport limited system includes the following:

* Deep, unconsolidated, poorly sorted bed material
* Angular particles
* Localized erosion that is not propagating upstream
* Deposited materials on top of bedrock and under bridge

The deep, unconsolidated, poorly sorted bed material also indicates that the system is dropping particles out of suspension in a relatively short time. If the tail of the hydrograph were long, the bed materials would be sorted with coarser material underlying the fine-grained sands. However, the material is just dropped out of suspension at roughly the same time as the water infiltrates into the substrate and quickly disappears. It is deep and unconsolidated, which indicates that it is readily transported with any significant flow. The system has the materials ready to be transported, but it is transport-limited because it is ephemeral.

The angular particles in the bed material indicate that the sediment is not being transported for long distances or for long periods of time. When sediment is transported, it rubs against the bed, bank, and other suspended particles. This will make each grain smoother and rounded. The presence of angular gravels and cobbles indicates that the system is only transporting materials for short times.

Localized erosion was observed in the field in a few locations (for example Photographs 8 and 12). However, this erosion is not propagating upstream. If the system were actively down cutting, the apron on the downstream side of the Barrel Creek Bridge would be severely undercut. But instead, there is a small drop indicating that sediment is not being actively eroded.

The loose sands being deposited on top of bedrock (Photograph 19) and under the bridge (Photograph 11) illustrate the deposition of material at the falling limb of the hydrograph. The grain size is small enough to be transported during any significant flow event. The system is sediment-transport limited.

2.2 Downstream Grade Controls

The second critical geomorphic observations made in the field are the downstream grade controls. A grade control is a critical component of a stream, because it limits the extent of any potential change in the stream gradient. The schematic in Figure 2 illustrates how a grade control limits the extent of erosion both upstream and downstream of the structure. The grade control will stop any upstream migration of head cuts. The grade control acts as a pivot point for the gradient of a river, so erosion upstream of the grade control is also limited.

During the field investigation, two grade controls were identified, as follows:

* Bridge at Barrel Creek (Photograph 9)
* Bedrock across river bottom (Photograph 23)

The upstream grade control is the bridge at Barrel Creek; it is a man-made structure. Because it is man-made, there is the potential that this structure may fail at some time in the future. The downstream grade control is made of bedrock that is erosion resistant, so it will continue to control the stream gradient for an extremely long time. These structures control the hydraulic gradient and therefore the stream power of the creek. The grade controls will limit the erosion capacity of the stream (Figure 2) and a control on depositional processes.

3.0 GEOMORPHIC IMPLICATIONS FOR DEVELOPMENT IN WATERSHED

Concerns have been expressed about the potential impact of the development of the proposed Rosemont Mine on the geomorphology of Barrel Creek and Davidson Canyon. Degradation of these channels, should it occur, could potentially affect the Outstanding Waters of Arizona located in lower Davidson

Canyon. The geomorphologic investigation that was conducted addresses this concern, indicating that the proposed mine development will have no significant impact on the geomorphology of either Barrel Creek or Davidson Canyon.

The geomorphology of fluvial systems is largely dependent on three factors: i.e., water flow, sediment characteristics and availability, and the geometry of stream channels. The justification for stating that the mine will not have a significant impact on Barrel Creek and Davidson Canyon can be formulated in terms of these three variables:

3.1 Sediment

* The area affected by the mine is roughly equal to about 13% of the entire catchment area upstream of the Outstanding Waters of Arizona, located in Davidson Creek (SWCA 2012). Changes in sediment load and runoff from such a small portion of the entire catchment will not have a significant impact on the fluvial geomorphology of the stream system.
* In the worst case, it is estimated that the impact of the mine on total sediment load upstream of the Outstanding Waters of Arizona will amount to a reduction of about 4% (SWCA 2012). This difference between current and predicted sediment load is within the statistical noise of the fluvial system. An estimated change of about a couple percent is therefore deemed insignificant.
* Abundant availability of loose sediment on the surface of the catchment surrounding Barrel Creek and Davidson Canyon will continue to supply directly sediment to the streams during rainstorm events, regardless of the presence of the mine. The amount of sediment thus supplied is greater than what the flowing water can carry, characterizing the transport-limited nature of the stream system.

3.2 Geometry

* The natural grade control that is characteristic of the stream system prevents riverbed degradation and will maintain the sediment transport capacity of the flowing water, regardless of the planned mine development. Maintaining the sediment transport capacity at historic levels and not significantly altering the sediment load to the stream will retain the current geomorphologic character of Barrel Creek and Davidson Canyon, regardless of mine development.

3.3 Water Flow

* It is uncommon for the catchment of Barrel Creek and Davidson Canyon to be subjected to large storm events covering the entire area. Instead, convective storms of limited size occur over portions of the catchment when it rains. The scattered nature of such storm events results in generation of sediment supply from diverse locations in the catchment at different points in time. It rarely happens that sediment would be generated simultaneously from the entire catchment. The nature of sediment supply based on the isolated nature of storms will remain and not be significantly impacted by the mine.
* The transport-limited nature of Barrel Creek and Davidson Canyon explains the non-degrading nature of the stream system. The nature of the stream system will remain unchanged because the change in sediment supply due to the presence of the mine is insignificant, and the sediment transport capacity of the water will essentially remain the same due to the presence of naturally occurring grade control features. It is therefore

reasonable to expect that the creek will not degrade; particularly not near the Outstanding Waters of Arizona in Davidson Canyon and beyond. The creek will remain in a state of quasi-equilibrium; expected from a semi-arid, ephemeral stream.

4.0 REFERENCES

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Hasan, M.A., R. Egozi, and G. Parker. 2005. Experiments on the effect of hydrograph characteristics on vertical grain sorting in gravel bed rivers. Submitted to Water Resources Research. November 1, 2005.

Reid, I., J.B. Laronne, and D.M. Powell. 1998. Flash-flood and bedload dynamics of desert gravel-bed streams. Hydrological Processes. 12, pp. 543-557.

SWCA. 2012. Characteristics of Davidson Canyon Watershed and Sediment Delivery. Memorandum to Golder Associates. July 12.

U.S. Forest Service (USFS). 2011. Draft Environmental Impact Statement for the Rosemont Copper Project, a Proposed Mining Operation, Coronado National Forest, Pima County, Arizona. September. p. 303.

Yang, C.T. 1996. Sediment Transport Theory and Practice. McGraw-Hill, New York.

FIGURES

Figure 1 **Site Location Map**

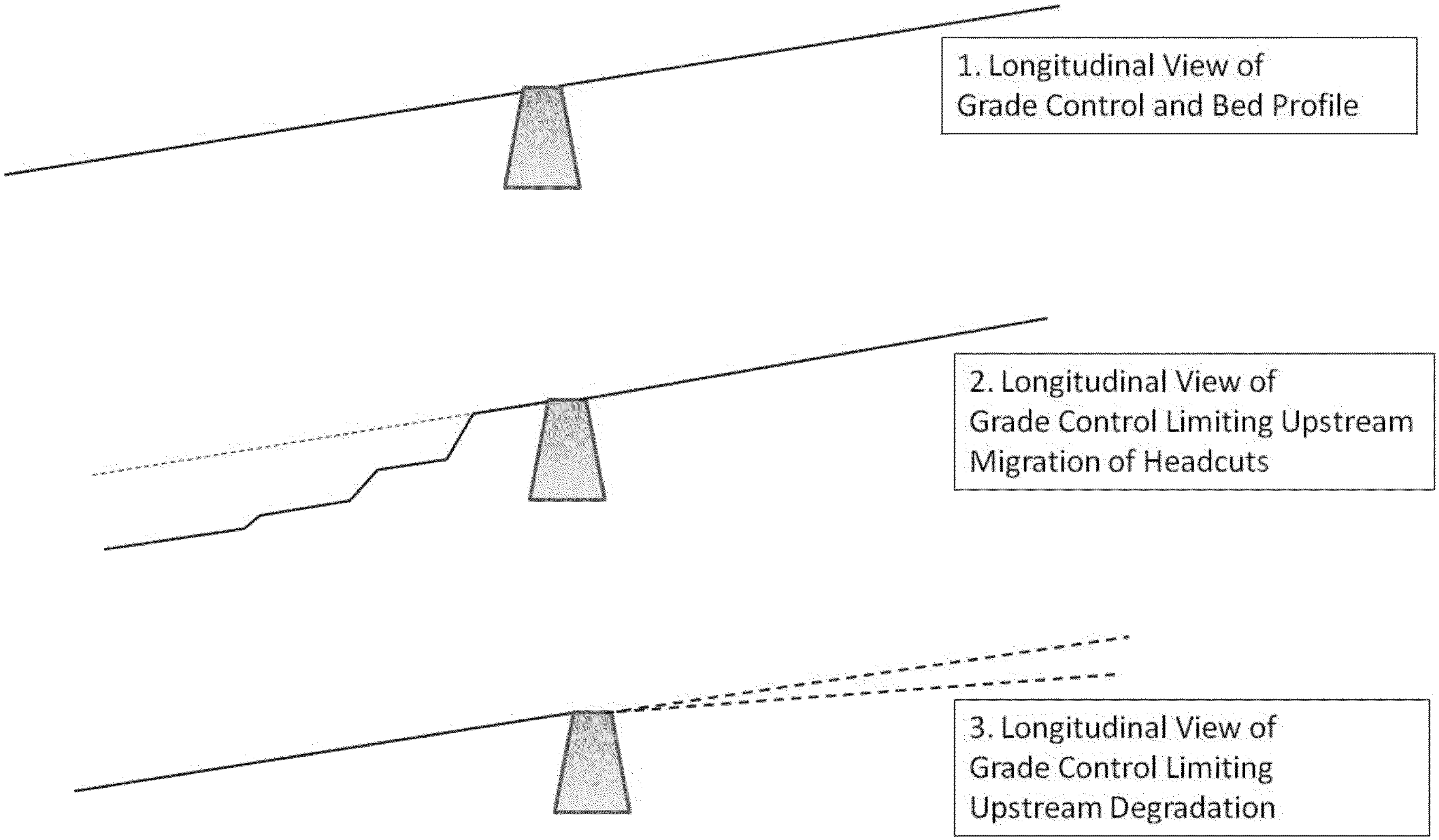

Figure 2 **Schematic Illustrating Geomorphic Implications of a Grade Control Structure**

PHOTOGRAPHS

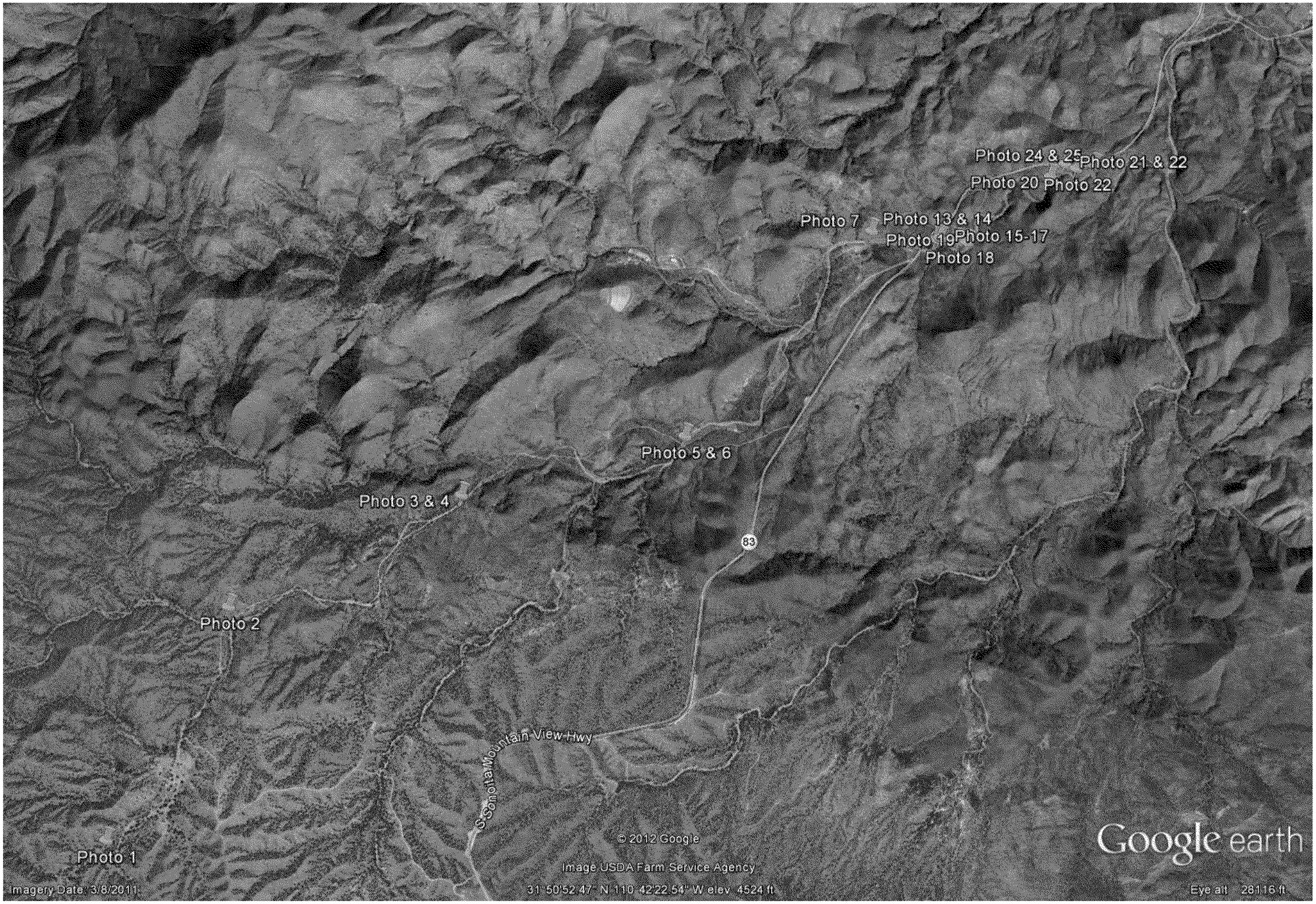

Photo 1 Photograph Locations

Photo 2 **Bed material in Upper Barrel Creek. Note angularity of cobbles.**

Photo 3 **Organics from flowing water caught in fence. These indicate that water levels were high in the recent past. However, there are fine-grained sands deposited at the same location. This indicates that the system is sediment-transport limited.**

Photo 4 **Barrel Creek looking upstream. Note the poorly sorted, unarmored bed material.**

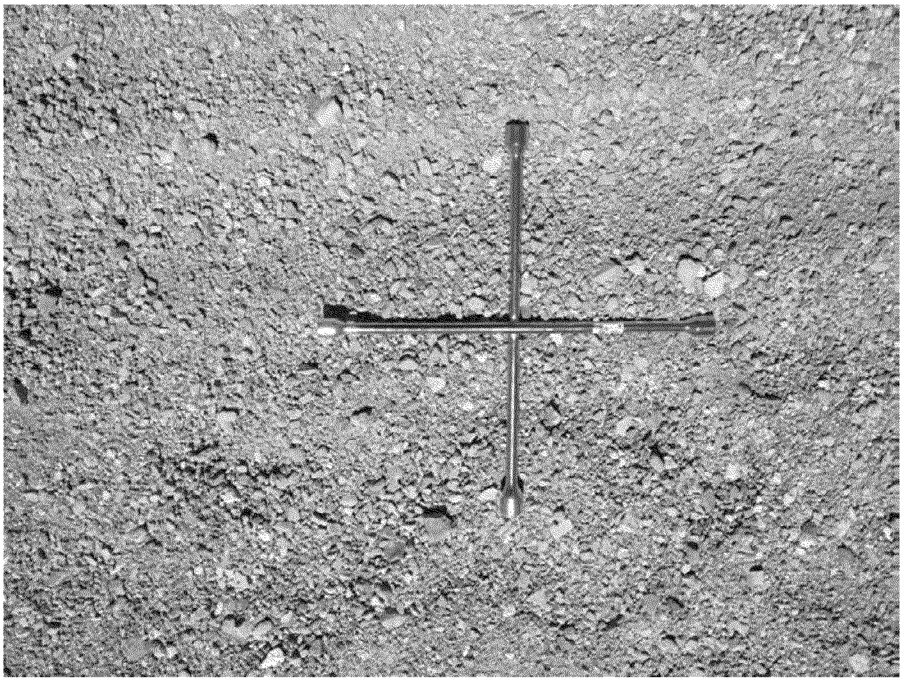

Photo 5 **Bed material in Barrel Creek. Note the poorly sorted, angular sands and cobbles.**

Photo 6 **Barrel Creek looking downstream. Note the unarmored, thick layer of sands and cobbles.**

Photo 7 **Organics from flowing water caught in fence. This indicates that high water was flowing in the creek in the recent history.**

Photo 8 **Barrel Creek looking upstream. In this location, the bed material is composed of sands and cobbles. The floodplain contains angular cobbles and boulders.**

Photo 9 **Small tributary into Barrel Creek. The erosion of this tributary will continue during the next large storm event. However, the erosion will cease when water stops flowing.**

Photo 10 **Barrel Creek Bridge looking downstream. Sediment has been deposited on the upstream side of the bridge. The bridge is a local grade control.**

Photo 11 **USGS gauging station 09484580 Barrel Canyon Near Sonoita, Arizona**

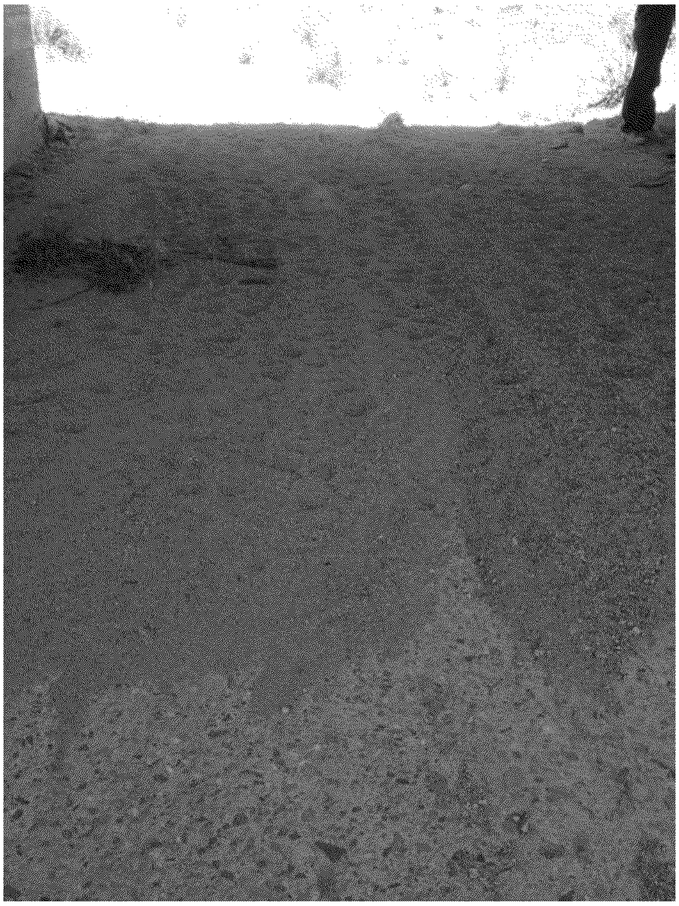

Photo 12 **Sediment deposited under bridge at South Sonoita Highway. The concrete apron is a local grade control structure.**

Photo 13 **Erosion on downstream side of apron at South Sonoita Highway Bridge. The erosion is relatively small given the large flows that occur in Barrel Creek. This is another indication of a sediment-transport limited system.**

Photo 14 **Deposition downstream of bridge. The water spreads out after flowing under the bridge, which decreases the transport capacity and deposits sediment.**

Photo 15 **Typical sandy bed material. This material will be readily transported during the next flow.**

Photo 16 **Typical colluvial, boulder-cobble bank material.**

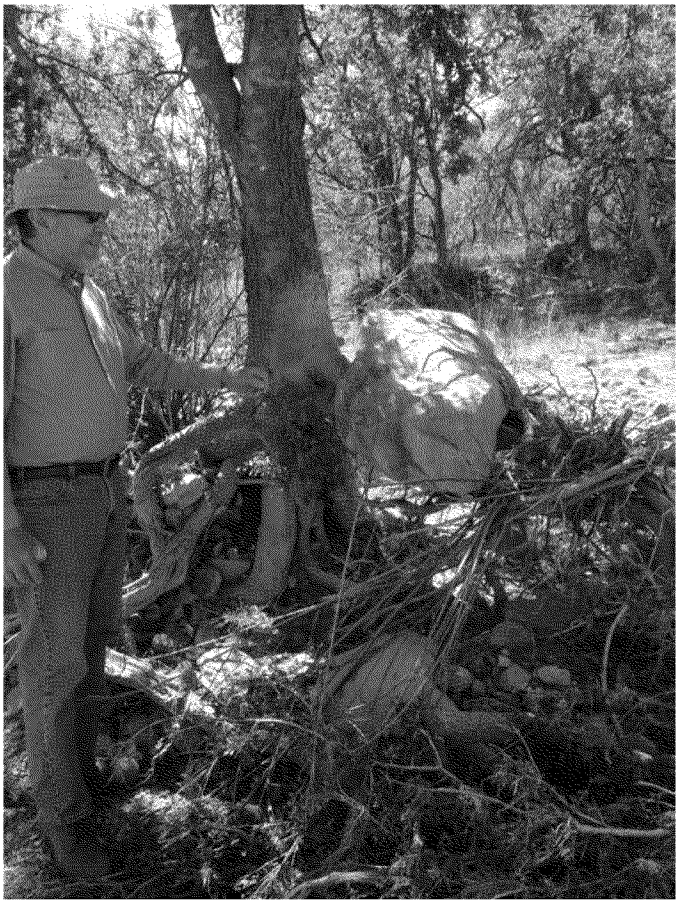

Photo 17 **Remnants of boulder bank material. Boulder was left hanging on the root while the smaller particle sizes were eroded.**

Photo 18 **Typical colluvial, boulder-cobble bank material.**

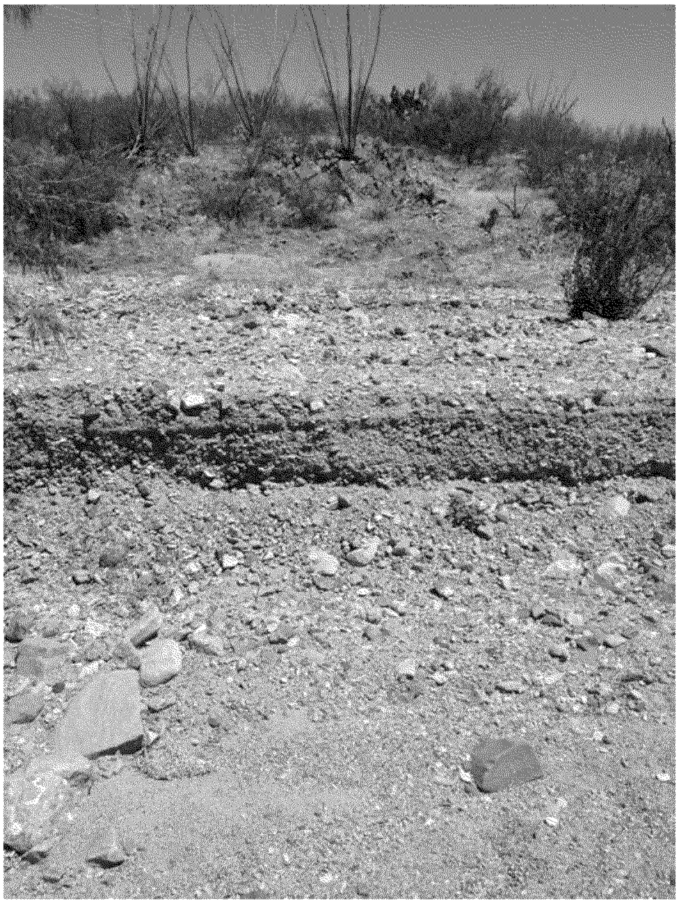

Photo 19 **Depositional, alluvial bank material. This deposition occurred on the downstream side of a large boulder.**

Photo 20 **Bedrock outcrop along bed and bank. The bedrock outcrop is covered with smaller-grained sands that fell out of transport during the falling limb of the hydrograph.**

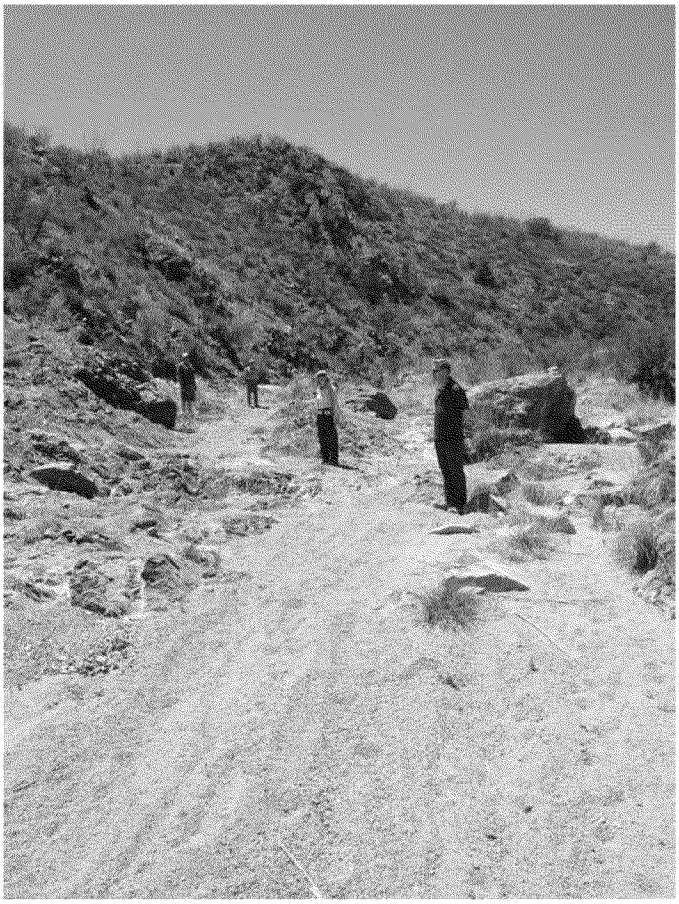

Photo 21 **Bedrock outcrop along bed. Multiple drops are identified by people standing at different levels. These outcrops are a local grade control for the creek.**

Photo 22 Seep identified within Barrel Creek.

Photo 23 Seep produced moist soil right at the bed surface.

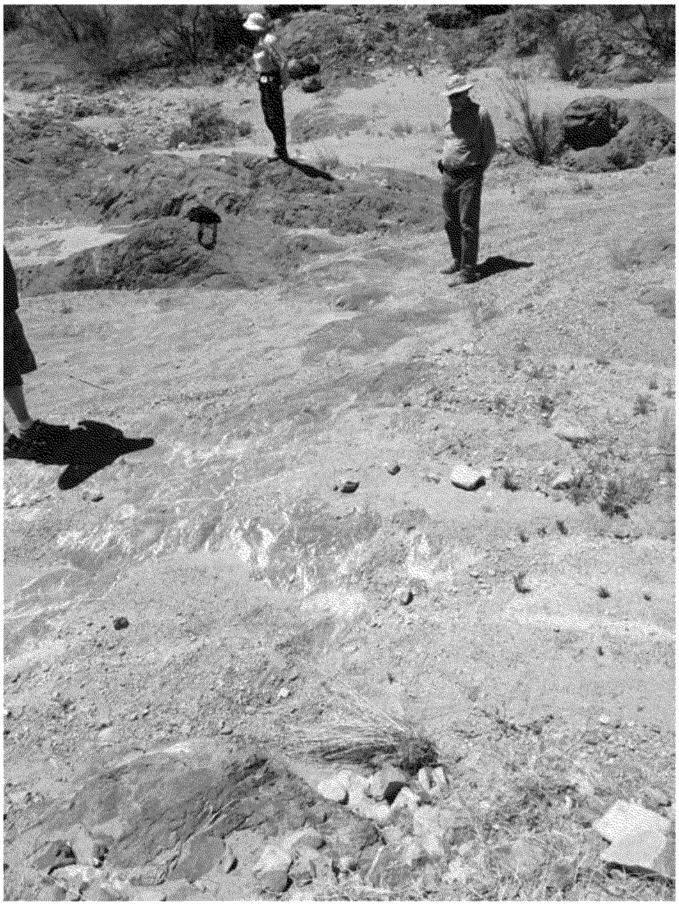

Photo 24 Bedrock grade control extending across entire width of channel.

Photo 25 **Sediment deposited upstream of pinch point. The pinch point in the stream is created by bedrock outcrops. A backwater effect happens during high flows, and sediment falls out of suspension on the upstream side.**

Photo 26 **Pinch point in stream indicating bedrock grade control.**